Calibration modelling and stability testing for the Kodak DC200 series digital still camera

Mark R. Shortis[a], Clifford L. Ogleby[a], Stuart Robson[b], Elias M. Karalis[b] and Horst A. Beyer[c]

[a]Department of Geomatics, University of Melbourne, Australia
[b]Department of Geomatic Engineering, University College London, England
[c]Imetric SA, Porrentruy, Switzerland

ABSTRACT

This paper reports on initial investigations into appropriate calibration models for and the reliability and stability of the calibration of the Kodak DC200 series cameras. Results of tests of different types of digital still cameras are compared, in general, to the DC200 series and then various calibration tests of a DC265 camera are presented and analysed. Block- and photo-invariant camera calibration models are compared to ascertain their suitability for the physical variability of the cameras. In conclusion, the paper makes some recommendations on the potential reliability and stability of the Kodak DC265 camera.

Keywords: digital still cameras, camera calibration, calibration stability, calibration models

1. INTRODUCTION

Digital still cameras are now universally accepted for use in close range photogrammetry and machine vision applications due to their advantages of high resolution digital images, convenience and portability of use, and rapid image download and data processing. For example, vision metrology systems incorporate digital still cameras as a fundamental component, used either as a single roving camera (offline mode) or in multiple camera configurations as part of a work cell arrangement (online mode). Further, the vast majority of reported applications of close range photogrammetry use digital imagery, typically from digital still cameras. The acceptance of digital still cameras is based principally on the demonstrated efficiency with which they can be used and the predicable and verifiable accuracy levels that can be achieved. The range of commonplace use spans industrial metrology, reverse engineering, heritage recording and biomedical applications.

For a number of reasons, vision metrology systems have tended to use "professional" digital still cameras, usually based on 35mm SLR or 70mm designs, or so-called scientific CCD cameras. Principal amongst the reasons for this preference has been the higher resolution CCD sensors associated with such cameras, although other considerations such as a greater range of features and the availability of interchangeable lenses are also factors. Professional digital still cameras incorporate onboard storage, a communications interface and a through-the-lens viewfinder, but are generally not designed with the stability and robustness required for photogrammetric applications. Whilst the scientific grade of CCD cameras generally have a much greater stability and robustness, they also have disadvantages such as the lack of onboard storage or a through-the-lens viewfinder in the absence of modifications or specialised designs. Cameras such as the Kodak DCS400 and MegaPlus series are typical examples of the two classes and are widely used.

At the other end of the scale have been consumer level digital still cameras with relatively low resolution CCD sensors and a limited range of features. Low resolution in particular, combined once more with poor stability and robustness, has generally restricted such cameras to very low accuracy applications. Due to the complex factors of falling costs from volume sales, rising consumer expectations, competitive marketing of cameras and advances in the technology, the threshold level of the low end of the digital still camera range has been steadily rising in terms of CCD resolution and camera features. Typical of this style of digital still camera is the Kodak DC200 series. The DC200 series does not have a through-the-lens viewfinder nor interchangeable lenses, but does have many of the other features of professional cameras such as the DCS400 series.

The most pertinent characteristic of the current range of consumer digital still cameras like the DC200 series is the price/performance comparison. These cameras are 10-20 times less costly than the DCS400 series, but have CCD sensor resolutions that are 50-100% of the professional cameras. For example, the DC265 has a 1536 by 1024 CCD array whilst the top of the range DCS460 has a 3072 by 2048 CCD array. Vision metrology systems developers have a demonstrated skill in quickly utilising advances in imaging technology, and it could be expected that the improving price/performance ratio of consumer digital still cameras will not escape their attention. Therefore it is inevitable that cameras like the DC200 series will be incorporated into metrology systems in the near future, and it is already evident that the reported use of consumer-style digital still cameras is increasing.

The DC200 series has the specific, added advantage of the Digita scripting language, which allows the camera status to be controlled at start-up or at any other time. To be used for photogrammetric purposes, a consumer camera must offer a manual mode of operation that disables features such as automatic focus, which would otherwise randomly alter the calibration. Script control of the camera is valuable for repeatable settings of manual focus distance, manual zoom and exposure settings. Relatively few consumer cameras have a scripting language and this can lead to problems with the consistency of set up due to the lack of fine control over settings such as manual focus and manual zoom. Digital still cameras such as the DCS400 and Megaplus series do have fine control over manual lens settings, or can have the lens taped into a fixed position, and so are not affected by the lack of control that is a real problem for many compact style consumer cameras.

2. CALIBRATION STABILITY STUDIES

The accuracy and precision of the derived photogrammetric data is dependent, amongst many other factors, on the accuracy and stability of the camera calibration. For the vast majority of photogrammetric applications, use of the simple case of a block-invariant calibration model comprising the primary physical parameters, including the principal point position, is sufficient. However, cameras designed for photojournalism and professional use, such as the Kodak DCS400 series cameras, are well known for their calibration instability because the design is based on a 35mm SLR camera body. In particular, previous research has shown that the principal point location is prone to movement during normal handling of the camera, due to the mounting mechanism of the CCD array[1]. It could be expected that consumer level products would be similarly affected by lack of stability and lack of robustness, because it is also the case that their design is not influenced by design constraints for metric use. As the DC200 series and other very similar cameras are likely candidates for inclusion in vision metrology systems, the suitability of this camera type is worthy of evaluation.

A number of previous studies of camera calibration precision, reliability and stability have indicated a variety of results for various cameras. For example, the Kodak DCS400 series camera has been subjected to many precision and accuracy tests[2,3]. In some cases the results have been contradictory or inconclusive, particularly because comparative tests are complex and difficult at the very fine point position tolerances provided by self-calibrating networks employed in conjunction with this camera. Straightforward testing has typically used the internal precision from self-calibrating networks as an accuracy assessment, using single epochs alone or multi-epoch comparisons of a stable array of targets with or without scale references. In all cases the DCS400 series cameras were assessed as having a very high level of reliability with proportional precision (ratio of the mean precision of the target coordinates to the largest dimension in the target array) levels in excess of 1:100,000. Internal precision levels better than 1:350,000 were reported by some of the authors for networks with photo-invariant parameters for the principal point location[1]. Corresponding RMS values in the image space have been as low as 1/50 of a pixel.

In contrast, relatively few studies of scientific and consumer digital still cameras have been reported. The Kodak Megaplus cameras used in vision metrology systems have been analysed using the standard internal accuracy test for a self-calibrating network. One early study[4] reported precision levels of the order of 1:50,000. More recent work by some of the authors[5] has reported precision levels of 1:50,000 to 1:80,000 for a Megaplus 1.6i camera, and precision levels up to 1:330,000 for a Megaplus 4.2 camera, with RMS image space precisions in the range of 1/30 to 1/45 of a pixel. Similar tests of Kodak DC210 and DC260 series consumer cameras carried out by some of the authors[6] reported RMS image space precisions in the range of 1/5 to 1/13 of a pixel and corresponding relative precisions approaching 1:30,000 in the most favourable cases. A test of the DC40 camera[7], a predecessor of the DC200 series, produced relative accuracies (as assessed against a target array pre-coordinated with a total station) of 1:8500 and RMS image space precisions if 1/10 of a pixel.

Still fewer studies of stability testing have been reported for digital still cameras. The most comprehensive testing of the DCS400 series has been conducted by some of the authors[3], and the general conclusions were that there were no statistically significant changes, either in the short or medium term, to the camera calibration parameters other then the principal point location, if the physical integrity of the camera was maintained. If the camera was disassembled or otherwise disturbed then significant changes were evident. The emphasis in this work was the effect of handling and remedial measures on the stability of the principal point location in the cameras, and the conclusions reached on the stability of the camera calibration parameters were no surprise based on long experience with photogrammetric cameras.

The important factors in the stability of the calibration of cameras are clearly the robustness of the housing, changes in the physical integrity of the camera and of course long term wear and tear. These conclusions are supported by other investigations carried out by some of the authors. Scientific CCD cameras, again Kodak Megaplus series, have been shown to have very stable calibrations[1,8], and indeed were used as reference against which the Kodak DCS400 series were compared. Extensive investigations of the stability of video camcorders used in underwater stereo-video systems have conclusively shown the relationship between physical disturbance of the camcorders and significant changes in the camera calibrations[9,10].

All of the reported studies on stability testing have used a similar approach. Self-calibrating networks with many targets, exposures and camera roll angles have been used to achieve a high redundancy factor and geometric strength, and therefore optimised precision, reliability and independence of camera calibration parameters. The camera calibration parameters and their derived precisions have then been subjected to statistical testing for differences between epochs of measurement. Essentially the same approach has been used for this research into the stability of the DC265 camera.

As far as the authors are aware only short (hours or days) or medium (weeks or months) term tests have been reported. An obvious restriction on long term testing over many months or perhaps years is the propensity for cameras to be damaged and repaired, reconfigured with different lenses, lost and replaced, or upgraded. Due to the speed of advances in contemporary technology, it is entirely possible that digital cameras will never be fully tested for long term stability purely due to the rate of equipment turnover.

3. SHORT TERM RELIABILITY AND STABILITY TESTING

A series of six calibrations of a Kodak DC265 camera were conducted during one day at Imetric SA in June 1999. Each calibration test comprised sixteen exposures of a target array with 160 targets. The target array consists of a 3m by 2m planar array of targets with additional targets on movable fixtures in the foreground to give 1m of depth. Each exposure was oriented toward the centre of the target array, producing a convergent network with 100% coverage for every image. In each case eight camera stations were used, with two roll angles at each station. The camera rolls were taken in no particular sequence, but did provide a variety of 0°, 90°, 180° and -90° roll angles throughout the networks. Each network contained approximately 3500 redundant measurements.

The camera was pre-programmed in each case with a script that set the manual focus to 3m, set the zoom to the widest setting and turned off the internal image rotation (a consumer feature that re-orients exposures to always appear upright). The first three networks were exposed in a rapid sequence, handling the camera carefully, broken only by the requirement to download the images and ensure that the exposures were complete and acceptable. The intent of these three network was to establish the reliability of the camera over a short time span and with consistent conditions. The remaining three networks were varied to test the stability of the camera. During the exposures of the fourth network the camera was shaken repeatedly to simulate rough handling. The camera was repeatedly powered off and powered on again during the fifth network to test the repeatability of the zoom and focus settings adopted by the camera. Before each exposure in the sixth network the lens barrel was lightly moved around relative to the camera body to ascertain the influence of lens cone stability.

Each of the six networks was processed with block- and photo-invariant parameter sets. In the block-invariant case, all camera calibration parameters were in common for all exposures used in the network. The calibration parameter set comprised the principal point location, the principal distance of the camera, two terms of radial distortion, two terms of decentring distortion and an image affinity term. The image affinity term, although often insignificant, has been demonstrated to be a function of image transfer or lens misalignment[11] and was included in the calibration set for that reason. This calibration parameter set and block invariance is the standard approach to additional parameter sets for camera calibration if it is assumed that the integrity of the internal camera characteristics is maintained during the exposures made for the network.

In the photo-invariant case, the principal point coordinates are independently derived for each exposure whilst all other parameters are in common for all exposures in the network. This approach was proven to realise the optimal results with Kodak DCS400 series cameras in previous experimental testing conducted by some of the authors[1]. As noted previously, this approach was adopted under the assumption that CCD array mounting systems are very similar in Kodak digital still cameras, and the apparent rotation of the CCD array with roll angle for the DCS400 series may also be exhibited by the DC265.

The results of the network processing for the six networks are summarised in Table 1. The table shows comparisons of internal measures of precision for the six networks and the block- and photo-invariant cases. It is clear from both the RMS image space residuals and the proportional precisions that the photo-invariant approach produces superior results for the network computations. On average, the improvements in the RMS image space residuals and the proportional precisions are 1.43 and 1.29 respectively.

Calibration	Camera	RMS Image Residual (Micrometres)			Prop. Precision (1 :)		
		Block	Photo	Ratio	Block	Photo	Ratio
1		0.87	0.56	1.55	37000	52000	1.41
2		1.06	0.69	1.54	33000	45000	1.36
3		1.03	0.76	1.36	34000	43000	1.26
4	Shaken	0.83	0.64	1.30	43000	50000	1.16
5	On-off	1.00	0.71	1.41	37000	48000	1.30
6	Lens move	1.05	0.73	1.44	35000	44000	1.26

Table 1. Comparisons of self-calibrating network results for the block- and photo-invariant parameter cases.

The significant differences between the block- and photo-invariant cases were expected, however the lack of significant differences between the two groups of three calibrations were not expected. It is apparent that the changes in handling of the camera did not have a substantial effect on the internal precision measures for the networks. The implications of these results are that even if the camera is badly handled or powered off and on, it will still produce consistent levels of precision.

Overall, the results for the block-invariant parameter cases are consistent with 1/10 of a pixel image space precision and 1:30,000 proportional precision from previously reported results. The photo-invariant parameter cases are a significant improvement with image space precisions reaching 1/15 of a pixel and proportional precisions reaching 1:50,000.

The significant differences are clearly evident in the principal point locations for the photo-invariant cases of the camera calibrations. Results for cases two and five are shown in figures 1 and 2, and the diagrams exhibit the characteristic clustering similar to the results of previous research with the DCS400 series cameras[1]. The distinct clustering shown for the second calibration is also the case for calibrations one and three. The clustering is somewhat less distinct for the fifth calibration, indicating that the power off and power on sequence does introduce some randomisation of the principal point locations, and this was similar to the results for calibrations four and six.

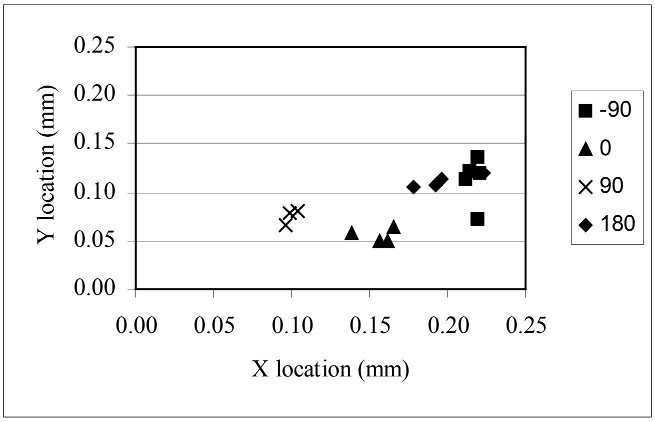

Figure 1. Principal point locations for calibration two, grouped by camera roll angles.

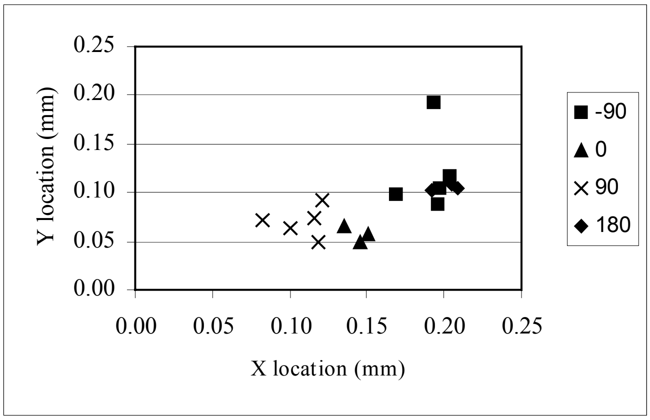

Figure 2. Principal point locations for calibration five, grouped by camera roll angles.

The clustering shown for the DC265 camera is clearer and more consistent than that for the DCS400 series cameras in the corresponding cases of a random pattern of 0°, 90°, 180° and -90° roll angles for the previous investigation[1]. In many of the sixteen calibrations of DCS420 and DCS460 cameras, the clustering was blurred or not evident, and was only very well defined in cases where the camera was consistently held in each roll angle whilst exposures were made. The pattern of principal point locations shown here are not the ideal response from the CCD array mounting, particularly because the 180° cluster is co-located with the –90° cluster, however this relatively small sample for one camera does indicate that the CCD mounting mechanism does behave in a predictable manner.

The different treatment of the camera however does have an influence on the stability of the calibration parameters between the calibrations. To detect changes in calibration parameters, a change significance parameter was computed in the same manner as previous research into calibration stability[3]. This value is the magnitude of the change in the parameter value, divided by the pooled variance of the parameters to normalise the value, and can be tested against a Student T distribution. In this investigation it is sufficient to analyse the behaviour of the parameters simply by comparison of values, however any value above 2 would be considered a significant change.

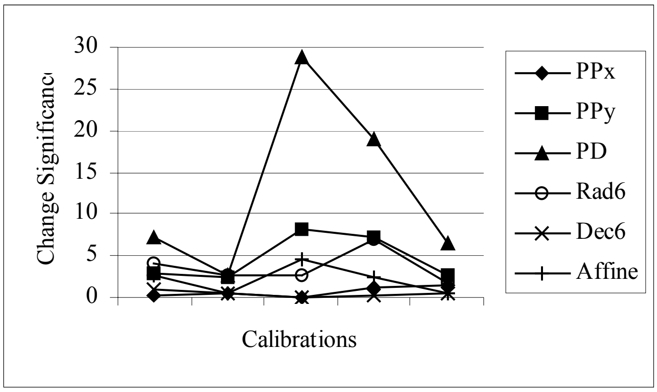

Figure 3. Calibration parameter changes for the calibrations with block-invariant parameters.

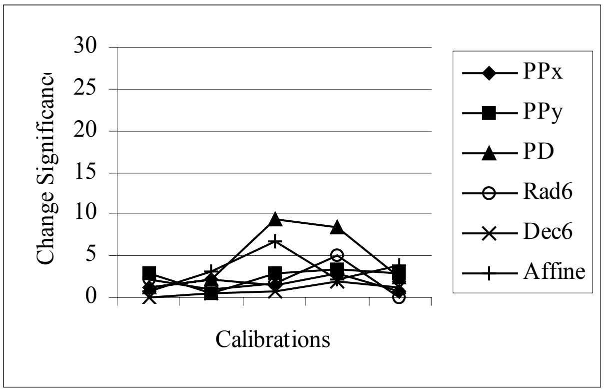

Figure 4. Calibration parameter changes for the calibrations with photo-invariant parameters.

The change significance values for the six calibration sets are shown in figures 3 and 4 for the block- and photo-invariant cases respectively. Values included are the principal point location in X and Y (the mean position was computed for the photo-invariant cases), the principal distance, radial and decentring distortion at a radius of 6mm, and the value of the image affinity parameter.

Once more it must be noted that this is a limited sample, however there is clearly a general increase in the change significance values between calibrations three and four, and the values of the change significances are greater for the second group of three calibrations. It is also evident that the results for the photo-invariant calibrations produce more consistent calibration parameters with more parameters having change significance below or near the critical value of two, indicating further support for the validity of this approach.

4. CONCLUSIONS

An integration of all of the above analyses indicates that that this particular DC265 camera produces quite reliable results in the short term, especially when used with a photo-invariant calibration set for the principal point location. Different handling of the camera did not unduly effect the measures of internal precision, suggesting that the internal consistency of the self-calibrating networks was not substantially compromised. Whilst there were significant changes to calibration parameters corresponding to inappropriate use of the camera, normal handling and use of the camera did produce consistent results.

Similar tests have been carried out on other DC200 series cameras, including repeated testing over a period of two months and accuracy tests against independently determined target array coordinates, and will be reported in a future paper.

REFERENCES

1. Shortis, M. R., Robson, S. and Beyer, H. A., 1998. Principal point behaviour and calibration parameter models for Kodak DCS cameras. *Photogrammetric Record,* 16(92) : 165-186.
2. Peipe, J., 1995. Photogrammetric investigation of a 3000 x 2000 pixel high resolution still video camera. *International Archives of Photogrammetry and Remote Sensing*, 30(5W1): 36-39.
3. Shortis, M. R. and Beyer, H. A, 1997. Calibration stability of the Kodak DCS420 and 460 cameras. *Videometrics V*, SPIE Vol. 3174, pp 94-105.
4. Brown, J. and Dold, J., 1995. V-STARS - A system for digital industrial photogrammetry. Proceedings, *Optical 3D Measurement Techniques III*, Karlsruhe, Germany, pp. 12-21.
5. Robson, S. and Shortis, M. R., 1998. Practical influences of geometric and radiometric image quality provided by different digital camera systems. *Photogrammetric Record,* 16(92) : 225-248.
6. Ogleby, C. L., Papadaki, H., Robson, S. and Shortis, M. R., 1999. Comparative camera calibrations of some "off the shelf" digital cameras suited to archaeological purposes. *International Archives of Photogrammetry and Remote Sensing,* 32 (B5) pp. 69-75.
7. Ahmad, A. and Chandler, J. H., 1999. Photogrammetric capabilities of the Kodak DC40, DCS420 and DCS460 digital cameras. *Photogrammetric Record,* 16(94) : 601-615.
8. Shortis, M. R. and Ganci, G., 1997. Calibration stability of digital still cameras for industrial inspection. *International Conference on Measurement Science, Technology and Practice*, Melbourne, Australia, pp 245-250.
9. Harvey, E. S. and Shortis, M. R., 1998. Calibration stability of an underwater stereo-video system: Implications for measurement accuracy and precision. *Marine Technology Society Journal*, 32(2) : 3-17.
10. Shortis, M. R., Miller, S., Harvey, E. S. and Robson, S., 2000. An analysis of the calibration stability and measurement accuracy of an underwater stereo-video system used for shellfish surveys. In press for *Geomatics Research Australasia.*
11. Fraser, C. S., Shortis, M. R. and Ganci, G., 1995. Multi-sensor system self-calibration. *Videometrics IV*, SPIE Vol. 2598, pp 2-18.